NSLS-II Accelerator Overview & Lessons Learned

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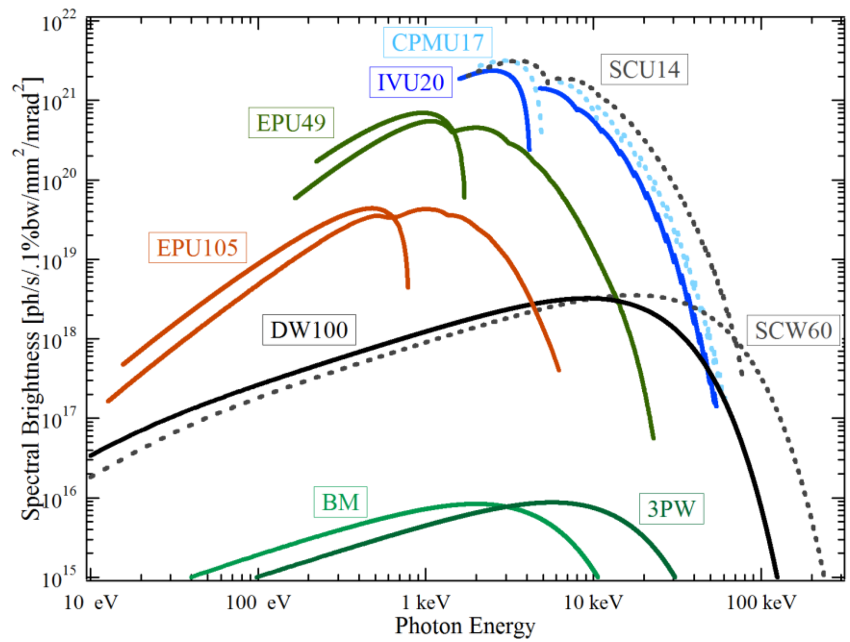
Outline

- Design features & project scope
- Phasing of installation
- Production and installation approach
- Review of accelerator installation (Injector & Storage Ring)
- Readiness and commissioning achievements
- Project performance
- Critical Paths identified
- Lessons learned
- Labor profile
- Challenges

NSLS-II Design Features

Highly optimized x-ray synchrotron delivering:

- Extremely high brightness and flux
- Exceptional beam stability
- Advanced instruments, optics, and detectors



Design Parameters

- 3 GeV, 500 mA, top-off injection system
- Circumference 792 m
- 30 Cell, Double Bend Achromat Lattice
  - 15 high-beta straights (9.3 m)
  - 15 low-beta straights (6.6 m)

Novel design features:

- Damping wigglers
- Soft bend magnets
- Three pole wigglers
- Large gap IR dipoles
- Long beamlines
- Ultra-high stability

Ultra-low emittance for high brightness and small source size

NSLS-II Project Scope

Accelerator Systems

- Storage Ring – 792m circumference
- Top-Off Injection System

Conventional Facilities

- Ring Building and Service Bldgs (400,000 gsf)
- 5 Laboratory/Office Bldgs (190,000 gsf)

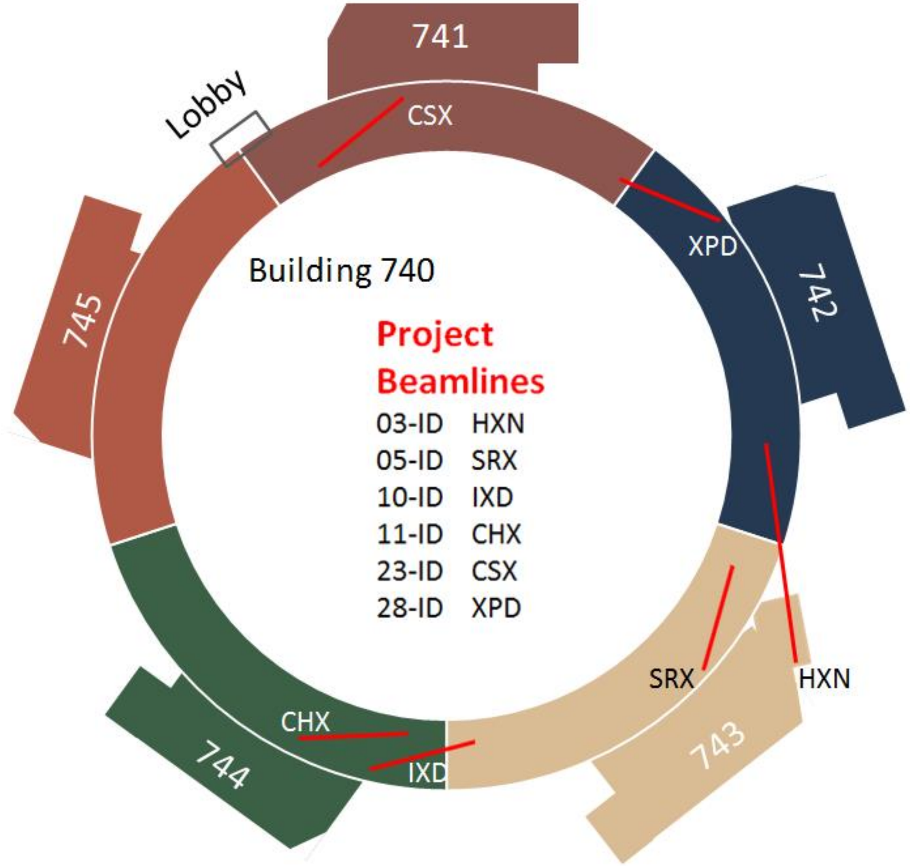
Experimental Facilities

- Capable of hosting at least 58 beamlines

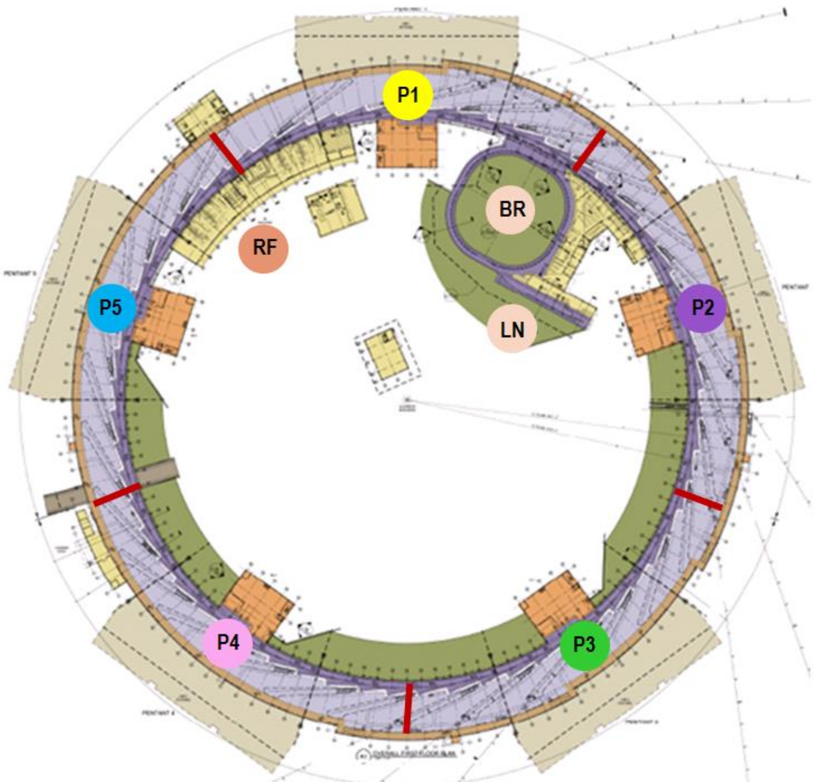
Research & Development

- Advanced optics & accelerator components
- Initial suite of 8 beamlines (two canted) (XPD, SRX, CSX, HXN, CHX & IXS)

Total Project Cost $912M (Baseline)



Phasing of Construction and Installation



Beneficial Occupancy		
Area	**Original Date**	**Actual Date**
Pentant 1 (P1)	1-Feb-11	14-Mar-11
RF Bldg. (RF)	23-Mar-11	16-Jun-11
Booster (BR)	18-May-11	12-Aug-11
Linac (LN)	18-May-11	12-Aug-11
Pentant 2 (P2)	2-Jun-11	21-July-11
Pentant 3 (P3)	27-Sep-11	21-Oct-11
Pentant 4 (P4)	28-Nov-11	21-Dec-11
Pentant 5 (P5)	9-Feb-12	29-Feb-12

- Received building in stages; temporary walls constructed
- Installation started as soon as Beneficial Occupancy was received (starting with Pentant 1 in March of 2011)
- LOB 1,3 & 5 - fully built and occupied
- LOB 4 - 50% complete/occupied

  (balance to be completed in the spring of 2015)
- LOB 2 - Shell is complete (currently used for storage)

Building Construction

Production and Installation Approach

Accelerator Production

- BNL procured Injector sub-systems (Linac, Booster Ring)
- BNL built and integrated Transfer Lines, Booster RF and SR components

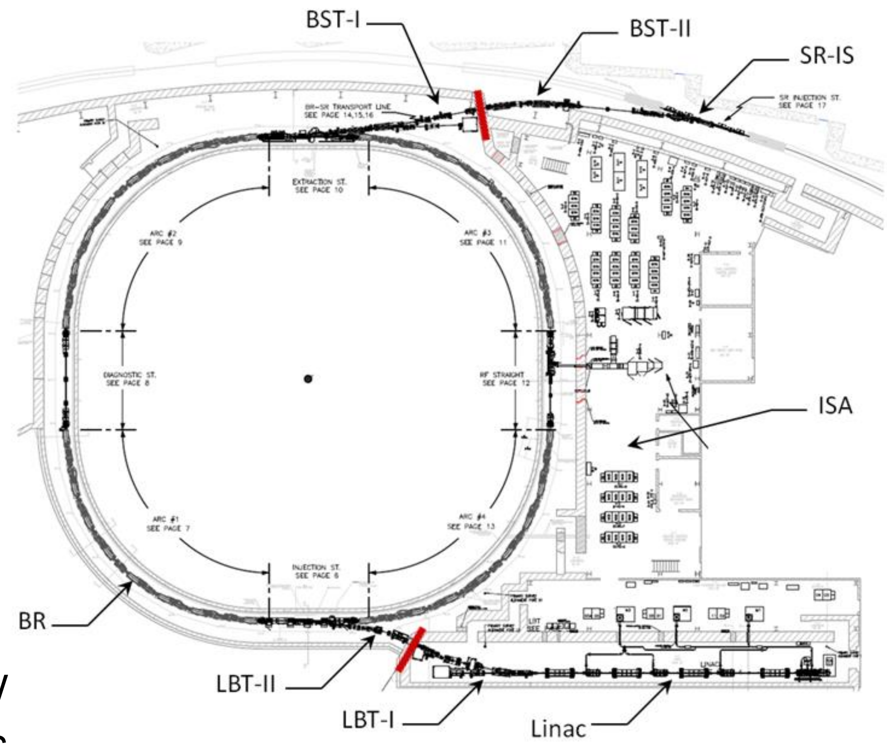
Accelerator Installation

• Linac	Vendor w/ BNL oversight
• Booster Ring	Vendor using BNL technicians for all hands–on work w/ vendor oversight
• Booster RF	BNL
• Transport Lines	BNL
• Storage Ring	BNL
• Storage Ring RF	Combination of BNL & Vendors

Injector

Linac

- 90 keV electron gun
- Four accelerator sections that accelerate electron beam to 200 MeV before it reaches the LtB Transport Line



LtB Transport Line

- Transports beam to the Booster
- Two dump lines located in the Linac vault, which provides opportunity to run just the Linac without injecting into the Booster tunnel.

Booster (3GeV)

- Accelerates electron beam from 200 MeV to 3 GeV
- Four Arcs, each equipped with nine magnet girders
- Four Straight sections (Injection, Extraction, Diagnostics & RF)

BtS Transport Line

- Transports beam to the Storage Ring
- One dump line located in the Booster tunnel, which provides opportunity to run just the Booster/Linac without injecting into the SR

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Linac & Transport Lines

Installation Milestone	Timeframe	
Linac	Nov ‘11	24 Mo
LBT-I	Jan ’12	
LBT-II	Dec ‘12	
BST-I	Feb ’13	
BST-II	Nov ’13	

Linac

Note: 24 months includes time to close Linac mis-steering event corrective actions (~ 1 year)

Transport Lines – (LBT & BST)

Booster Installation

Milestones	Completed
Mechanical utilities installed	Mar ‘12
First girder installed	Feb ‘12
Last of 46 girders installed	July ‘12
RF cavity installed and tested	Jan ‘12
System integration	Jan ‘13
Unit testing	Mar ‘13
Integrated testing	Mar ‘13
Supplemental Shielding	July ‘13
PPS hardware installed	July ‘13

10 Mo Accelerator hardware

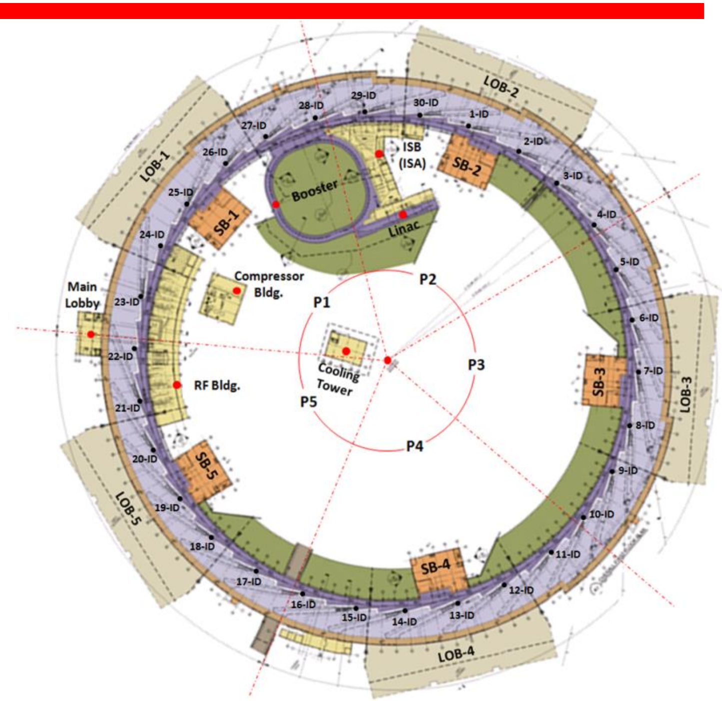
Total duration – Approximately 16 months

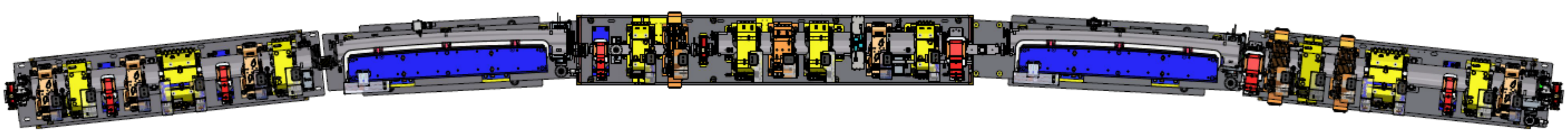
Injector Supplemental Shielding

**** Over 100 Supplemental Shields installed**

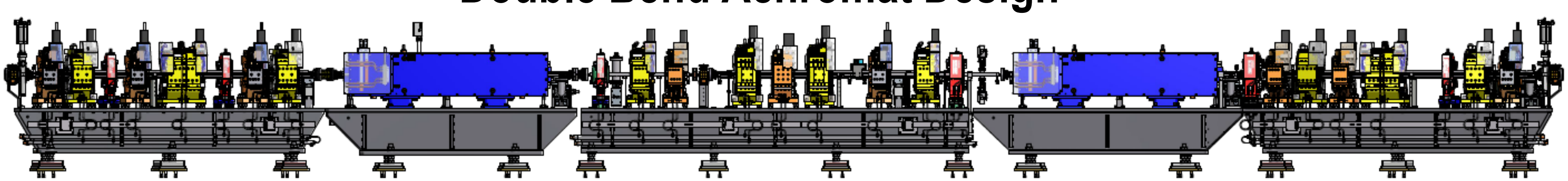
Storage Ring

- SR tunnel is comprised of five “Pentants” with each “Pentant” having six cells
- Each cell has one straight section and five Girders
- Straight sections will be occupied by IDs except at Injection and in two RF Cavity Straights
(27 Straights will be available for IDs)
- Girders are equipped with magnets, vacuum components and advanced instrumentation





Double Bend Achromat Design



SR Girder/Magnet Installation

Dedicated Integration facility

- Assembly and Integration including vacuum chambers and some instrumentation.
- Magnet-magnet alignment (< 30um)

Dedicated magnetic measurement lab

- Vibrating Wire
- Rotating Coil
- Hall probe

(150) Magnet Girders installed in tunnel

- Girder-girder alignment in tunnel (< 100uM)
  - 60 Dipoles
  - 300 Quadrupoles
  - 270 Sextupoles
  - 270 Correctors
  - 4 Bumps (Kickers)
  - 1 Injection Septum

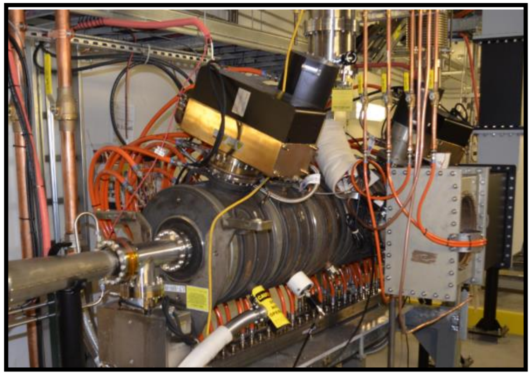
Over 900 Magnets Installed

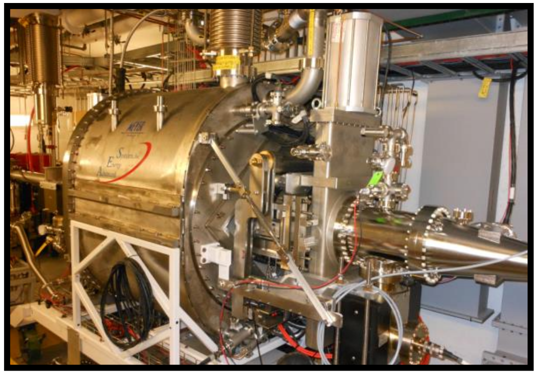
Mechanical Utilities

- **14 Secondary Pump Skids**
  - 9 copper skids (Magnets, Absorbers, RF Transmitters, Booster Cavity, Beam Lines)
  - 5 aluminum skids (Vacuum chambers)
- **DI drops in SR tunnel**
  - Multipoles
  - Dipoles
  - Vacuum chambers
- **Process Chilled Water**
  - PCW cools racks located on tunnel mezzanine
- **AC power**
  - AC runs from “power centers” to racks
  - Cables pulled from racks through offset conduits (labyrinths) into SR tunnel

Storage Ring RF System

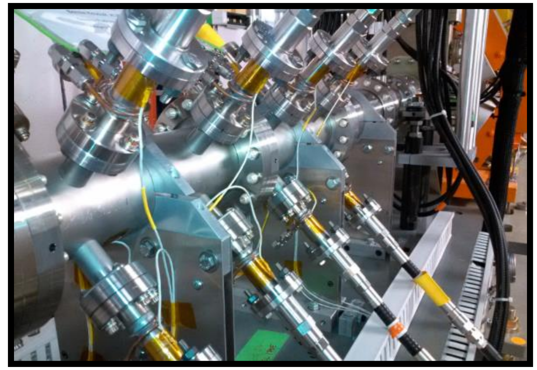
- **RF Transmitter (300KW)**
- **RF Cavity**
  - *Phase I commissioning* (mitigated SC Cavity delay)
    - 7 Cell Copper Cavity (Booster spare)
  - *Phase II Commissioning*
    - 500 MHz Superconducting RF Cavity is now installed and being used for commissioning at higher current
- **Cryo system**
  - Closed loop LHe system
  - LN2 system to provide pre-cooling
- **RF Blockhouse**
  - Used to test RF equipment prior to installation in the tunnel

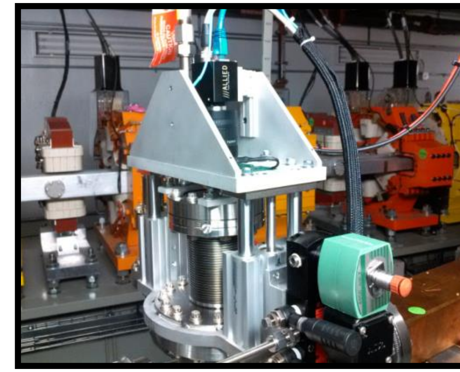


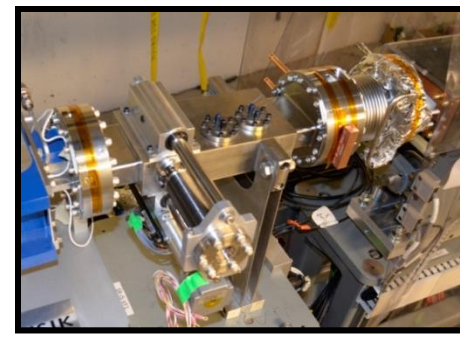


Storage Ring Instrumentation

- (180) SR-RF BPMs
- (18) SR-ID BPMs
- (1) SR-XBPM
- (1) DCCT
- (1) SLM
- (5) Beam Loss Monitors
- Bunch-by-bunch feedback
- (1) Tune Monitor System
- (5) Scrapers - Horizontal/Vertical







- One Storage Ring Flag located in the Injection Straight
- Beam alignment Flags planned for all Front Ends (currently 6 installed)
- Dedicated X-Ray diagnostic beamline with a pin-hole camera
- Dedicated beamline with a 90^{o} bend leading to SLM Hutch

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Insertion Devices

Insertion Devices installed to date:

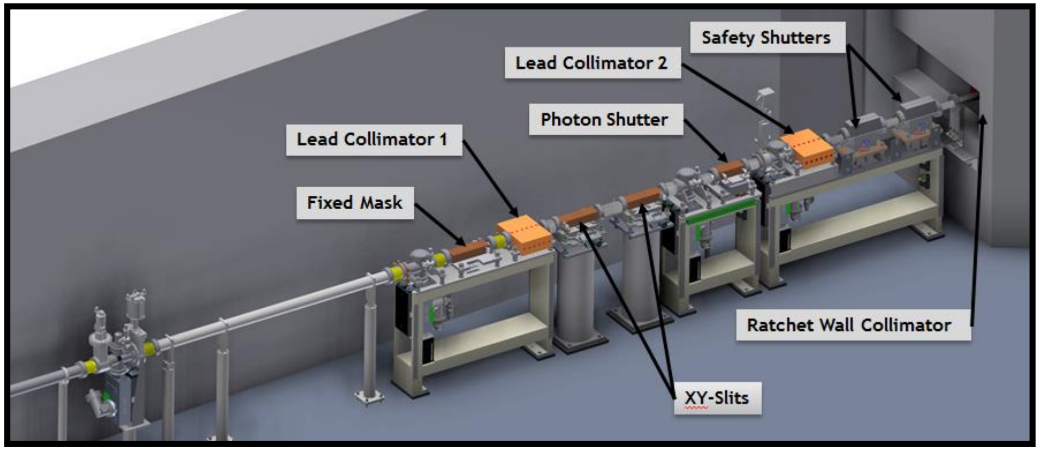
- (6) Damping Wigglers
  - (2) XPD
  - (4) Will be used on future beamlines
- (1) 1.5m IVU21 (SRX)
- (2) EPUs (CSX)
- (2) 3m IVU20 (HXN & CHX)
- (1) 3m IVU22 (IXS)

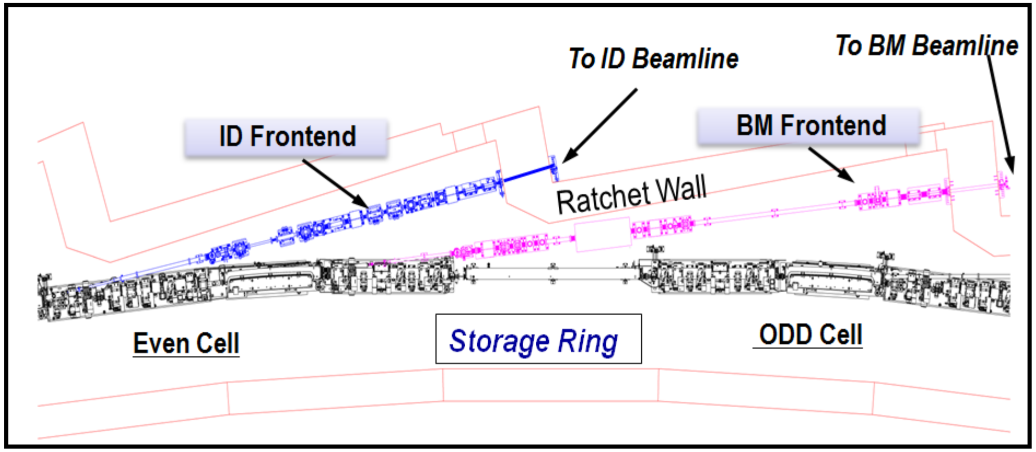
Time saving preparations:

- Tunnel floor prepared & cable trays installed in advance
- Rack installation & cable pulling is immediately performed after ID measurement are conducted
- ID specific vacuum chambers are installed just prior to ID installation (IVUs not included)

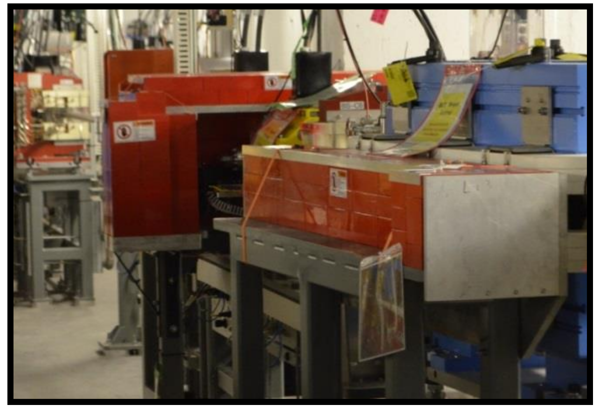
Front Ends

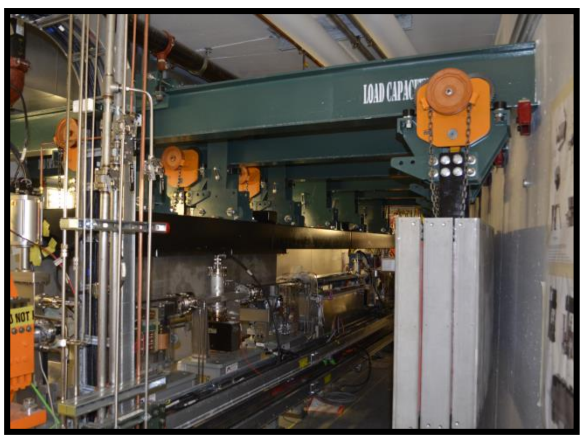
Six fully functional ID Front Ends installed to date: (XPD, SRX, CSX, HXN, CHX & IXS)

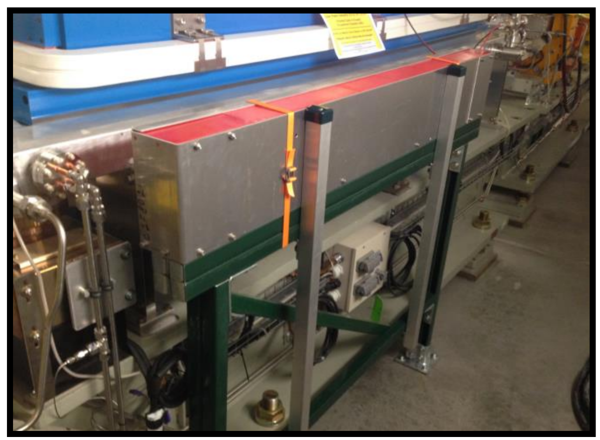




SR Supplemental Shielding





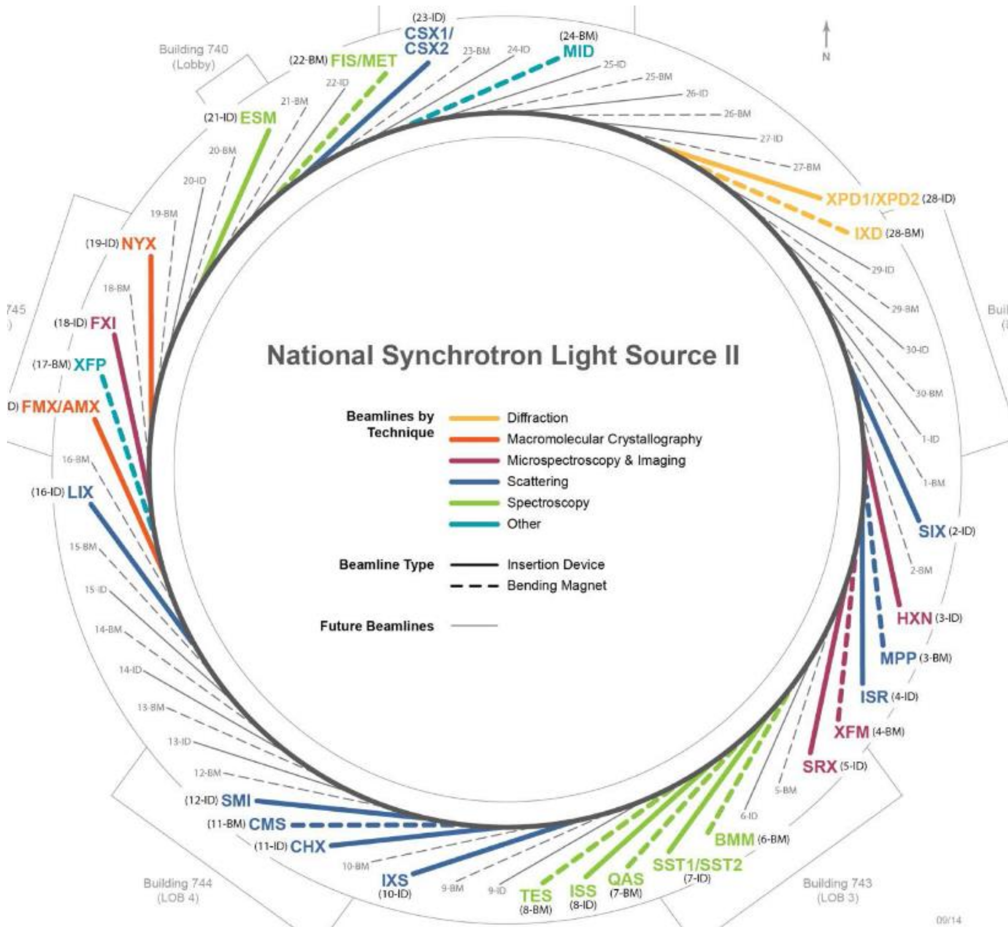


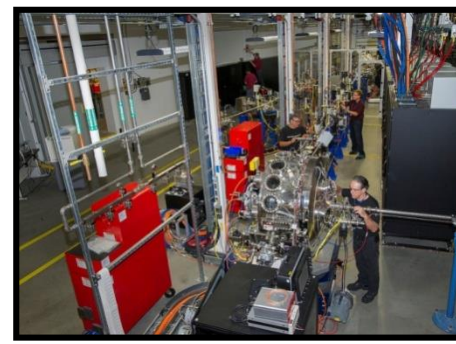
** Over 250 Supplemental Shields installed

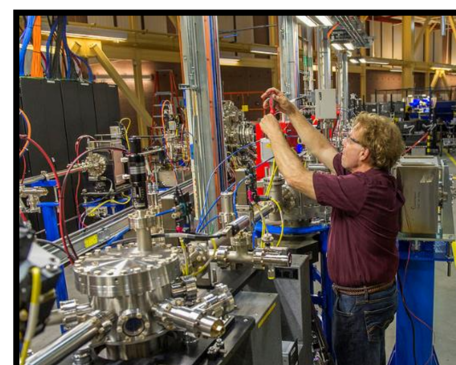
Experimental Beamlines

Six beamlines now being commissioned

(XPD, SRX, CSX, HXN, CHX & IXS)







Readiness & Commissioning Achievements

Booster	Completion Date
• IRR	Sept 2013
• ARR	Nov 2013
• Commissioning	Feb 2014
Storage Ring	
• IRR	Jan 2014
• ARR	Feb 2014
• Commissioning w/ 7 Cell Petra RF Cavity	May 2014
• Commissioning w/ Superconductive RF Cavity	Aug 2014
Beamlines & Operations	
• IRR Group A (XPD & CSX Beamlines)	Aug 2014
• Commissioning of IDs & FE	OCT 2014
• IRR Group B (HXN, SRX, IXS & CHX Beamlines)	Oct 2014
• Commissioning of IDs & FE	Dec 2014 (expected)

NSLS-II Project Performance

Achieved excellent technical, cost & schedule performance

- Installation and commissioning milestones met on October 2014
- Cost Performance

	Baseline	Actual
Conventional Facilities	$310M	$311M
Accelerator Systems	$295M	$314M
Experimental Facilities	$84M	$93M
Pre-Ops	$55M	$56M
Project Management	$68M	$70M
R&D	$61M	$61M
	$873M	**$905M**

- Baseline total with contingency = $912M

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Critical Path Activities

- SR & TL magnets (delivery and magnetic measurements)
- SR power supplies (installation)
- Pulsed magnets (design, fabrication and testing)
- Area Radiation Monitors – (delivery and testing)
- Supplemental Shielding (specification, design, fabrication & installation)
- Insertion Devices (delivery and magnetic measurements)
- Survey and Alignment (profiling of Girders in tunnel)
- SR RF Cavity (delivery & testing - mitigated by warm cavity)
- RF Cryo system (delivery and installation)
- PPS (software development, testing and certification)
- Readiness reviews (documentation for IRRs/ARRs)

Lessons Learned - General

- Bi-weekly meetings with "project controls" staff was essential
- Strong relationships between AD, PD and CF proved to be invaluable
- Importance of signage on barriers and methods of use
- Storage space considerations
  - Building delays required alternative storage solutions (secondary buildings, storage containers, cages on the experimental floor)
- Installation Coordination started well over a year before installation began
- Dedicated rigging teams are needed to affectively plan and schedule work
- A dedicated MRP system should have been obtained early on to facilitate efficient planning and control including:
  - Incoming receiving
  - Inventory control
  - BOM development for procurement and fabrication purposes.

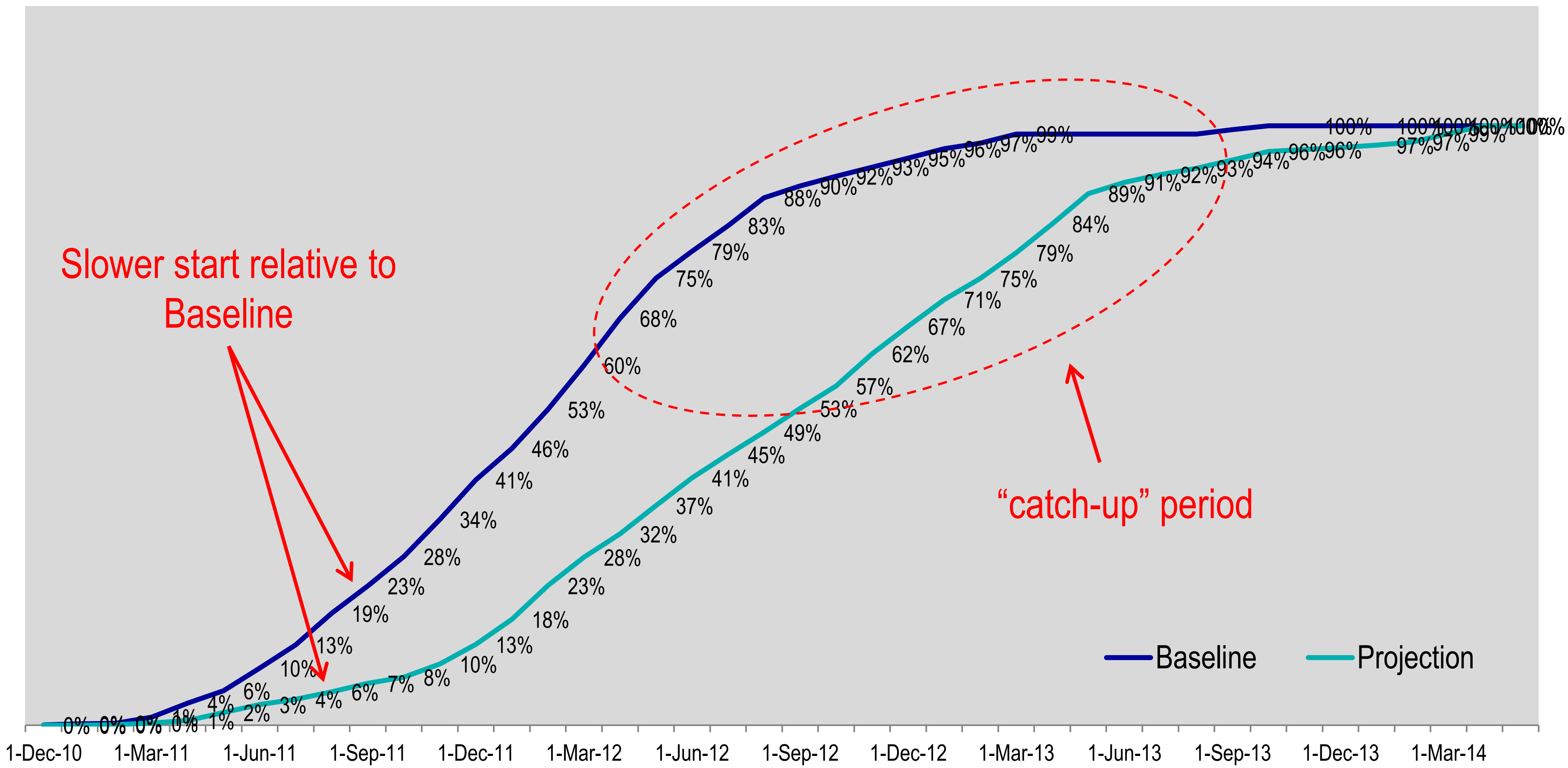
Lessons Learned - Coordination

- "Installation Coordinator" reported directly to the Division Director
- Installation Coordination started well over a year before installation began
- Identified "Work Control Coordinators" for each group (enhanced planning of work and general safety)
- Wrote work plans prior to work starting (beware of scope creep)
- "Plan Of the Day" meetings held every morning on site
- Plan of the day information updated daily with activities & safety warnings
- Weekly installation coordination meetings for the Storage Ring and Injector were very effective
- Weekly "coordination walk-throughs" were scheduled to identify and resolve hardware conflicts
- Strong coordination with Conventional Facilities & Photon Division was essential
- Space limitations in the Injector complex required detailed planning & coordination
- Importance of barricades & signage

Lessons Learned - Labor

- Learning curves & setup was longer than expected, which led to slow ramp-up
- Installation "work profile" had a prolonged peak due to shifted work
- Time associated with preparing for IRRs & ARRs was not planned
- Competition for survey/alignment resources
- Dedicated rigging team for project
- Underestimated labor for:
  - Shielding analysis & design
  - Electrical utilities & cable pulling
  - Mechanical utilities software effort
  - Rigging
- Resource leveling & schedule analysis performed to determine true schedule impact of delayed work & developed plans to mitigate
  - Additional temporary labor added to keep schedule on track
  - Some activities strategically shifted
- Schedule shifted from hardware driven to labor driven

Accelerator Installation Progress
(percent complete)



Includes SR, Injector, PPS & Insertion Device Installation WBSs

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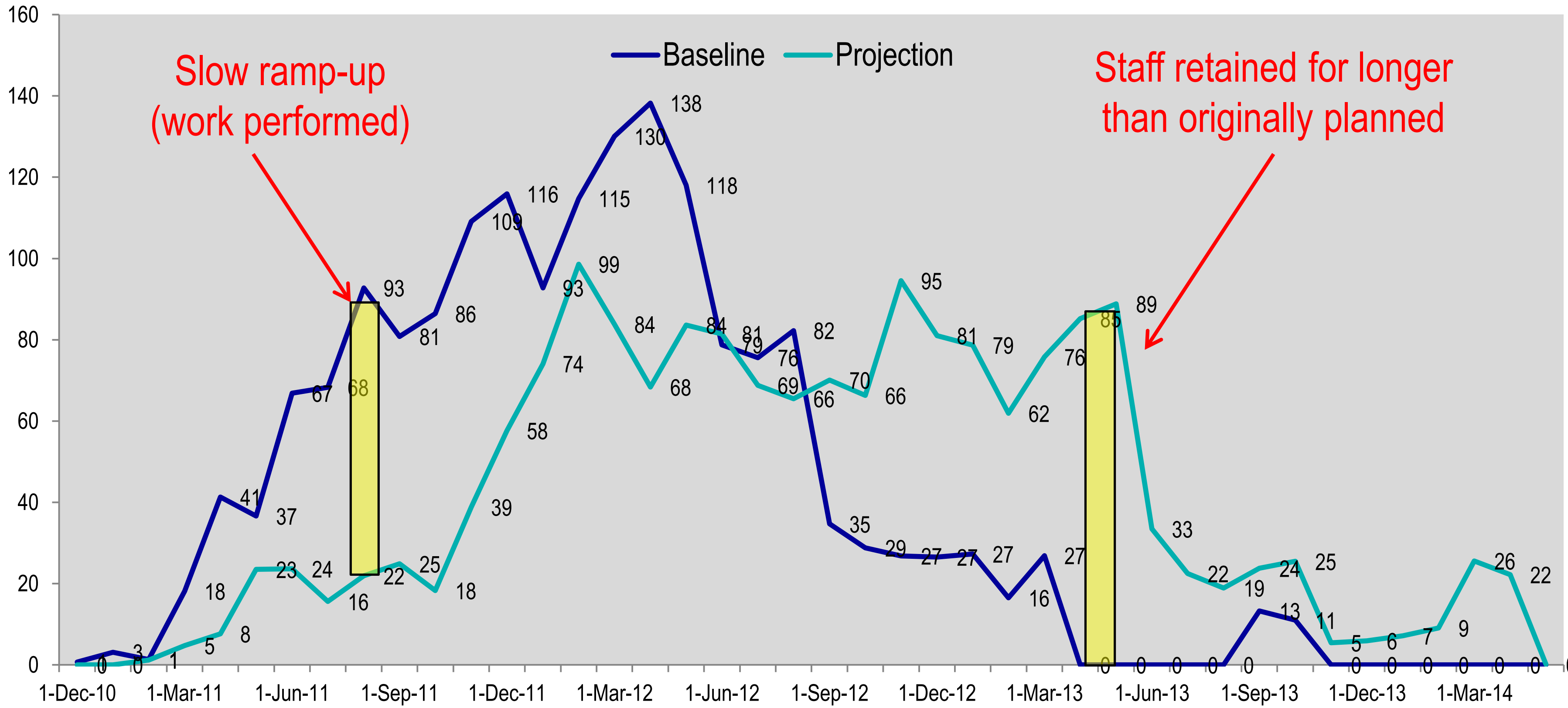
Accelerator Installation Work Profile
(FTEs)



Includes: SR, Injector, PPS & Insertion Device Installation WBSs

Challenges Experienced

- Delayed "beneficial occupancy" of ring building made planning difficult
- Extensive punch-list after receiving beneficial occupancy
- Coordinating multiple activities & teams during installation
- Coordination to avoid interferences between systems (walk-downs required)
- Difficulties associated with performing installation, integrated testing and commissioning in parallel

    example: Access to Pentants 1 & 2 limited during Booster commissioning
- There were limitations associated with having only one ID measurement lab
- SR Supplemental Shielding design, construction and documentation (> 350 Shields)
- Shortage of specialized installation labor
- Component delays (i.e. magnets, RF cavity, etc.) required additional planning to balance activities and resources.
- Limited floor space for staging materials and performing secondary installation activities
- Transportation of material during & after Hutch installation is often difficult

NSLS-II Project Success

- 3 GeV Accelerator has been commissioned up to 50mA
  (project milestone achieved – reaching higher currents over this next year)
- Commissioning of six Insertion Device “project” beamlines underway
- CD 4 planned for February 2015
- Construction of additional beamlines already underway

Proper *planning* and *coordination* are the keys to success.